NASA TECHNICAL NOTE

NASA TN D-2316

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NASA TN D-2316

DEVELOPMENT OF A 1200 FOOT ENDLESS-LOOP TAPE TRANSPORT FOR SATELLITE APPLICATIONS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1964

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SUMMARY

The tape recorder development described herein is a low power, two speed recorder whose unique endless-loop cartridge stores 1200 ft of 1/4 in. wide lubricated magnetic tape. A maximum mechanical power of 1.29 watts is required to drive the transport at 30 ips at 0 °C. During operation in the record mode at 3-3/4 ips tape speed only 0.083 watt of mechanical power is required at 0 °C to operate the transport. Speed reductions are obtained through the use of accurately machined pulleys and seamless polyester film belts. Although the optimum motor has not been obtained at this writing, wow and flutter measurements have been obtained at 1.14 percent p-p from 0-1000 cps bandwidth.

Included in this report is a discussion on the problems that arose with the tape during tests and the resultant solutions. The exceptional performance is made possible by the use of the unique tape cartridge and the accurately machined capstan assemblies which have less than 50×10^{-6} in. total indicated runouts. Duplex preloaded bearings are utilized throughout the transport. The mechanical portions of this transport have survived sinusoidal vibrations at 10 g from 5 to 2000 cps for 18 min and random vibrations at 20 g rms from 20-2000 cps for 4 min.

This paper describes in detail the design of the various components of this advanced tape recorder.

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INTRODUCTION

Tape recorders are an essential part of any spacecraft instrumentation where data gathered by sensors must be stored until a position is reached in orbit when the spacecraft can be conveniently interrogated. At this point the recorder sends the information to the ground station through the spacecraft transmitter.

The main reason an endless-loop recorder is preferred to a two reel system is that multiple interrogations can be made without exceeding the required playback time to a ground station. That is, a satellite can be interrogated several times before an orbit is completed without the information loss which occurs in a two reel system. Additional advantages of an endless-loop system are that tape reversing mechanisms are not necessary, end-of-tape sensing devices are not required, momentum compensation is relatively simple, the single reel provides compact storage, and the tape velocity is in the same direction for both record and playback modes, minimizing errors due to tape skew and alignment.

The advent of interplanetary capsules and large satellites where considerable data are to be stored necessitates large capacity endless-loop tape recorders. Endless-loop recorders with storage capacities of 200 ft of tape* are no longer satisfactory for some designs. Recorders with capacities of 1200 ft of tape or more are required. In addition, a rigid set of design specifications must be employed to assure long life and reliability. New design considerations, with respect to obtaining a functionally operational recorder, are required to achieve the flutter, low power, long life, and low weight necessary for the recorder's increased storage.

One design parameter that must be investigated is tape life. Included in this term "tape life" are the deterioration of magnetic properties, abrasion loss of the lubricant, edge wear, and the basic characteristics of the Mylar base material and oxide binder. Each one of these considerations is affected by one or more of the following: temperature, tape velocity, mean pack diameter (which determines the slippage between outer and inner tape diameters), and total recorder operational life required. Because of these tentative trouble areas, just a larger cartridge to accommodate the larger tape lengths will not solve the problem.

*Falwell, R.C., Stark, K.W., and White, A.F., "A Precision Endless-Loop Magnetic Tape Recorder for Space Applications," NASA Technical Note D-1542, February 1963.

Another area to be considered in the design is the selection of the proper motor. Again, simply utilizing existing motors as used in other tape recorders will not work. The power requirements are different, and motors must be matched to the recorder to prevent undesirable hunting which produces detrimental flutter and wow.

Capstan design (including bearing preload techniques, machining tolerances, material, and assembly and mounting arrangements) determines to a great extent how the instrument's performance will be affected by such disturbances as flutter and wow, skew and amplitude variations, etc.

Last but not least of the major design considerations is environmental testing. A 1200-ft. endless-loop recorder is much more sensitive to temperature and vibration testing than a small compact 200 ft. endless-loop recorder is. The large loop tends to be very erratic under random and sinusoidal vibration tests if left in a free condition in a cartridge.

The objective of this paper is to describe in detail the problems that arose and the solutions that were applied in the "in-house" design and development of a 1200-foot endless-loop tape recorder. The contents of this paper will be concerned with the initial development phase of the recorder.

OPERATIONAL DESCRIPTION

The 1200 ft. endless-loop tape recorder is a lightweight, low power, two speed system. The overall external dimensions are 13-3/8-in. in diameter and 3-1/2 in. in depth; it weighs 10 lb.

Figure 1 shows how an endless-loop cartridge operates. The tape is first wrapped onto the reel (g) and rollers (ℓ) by starting the first wrap at the edge of the reel and the tapered portion of the rollers. Successive wraps are built up progressively towards the edge of the rollers until 1200 ft. are contained. The two ends of the tape are brought up through the tape guide plate (k) and are spliced to form an endless loop. When the cartridge is in operation, the tape is pulled from the first wrap on the reel by the capstans (m) and it wraps back onto the outside of the tape pack. As the tape moves at constant velocity, each layer of tape slips upon the other providing tension to pull the tape back down into the cartridge on the return side (j). The operation of this recorder can be broken down into two basic modes, record and reproduce. When the recorder is operating in the record mode, the dual capstans are driven at 287 rpm. The rotating capstans impart linear velocity to the magnetic tape, drawing it across the face of the heads. In the reproduce mode, the capstans operate at 2296 rpm yielding a record-reproduce ratio of 8:1.

The 1/4-in. lubricated Mylar base magnetic tape accepts four signal channels. During each orbit, one information and one timing channel are recording a signal; therefore, with a tape record speed of 3-3/4 ips, 64 min. of information can be recorded. The stored information is

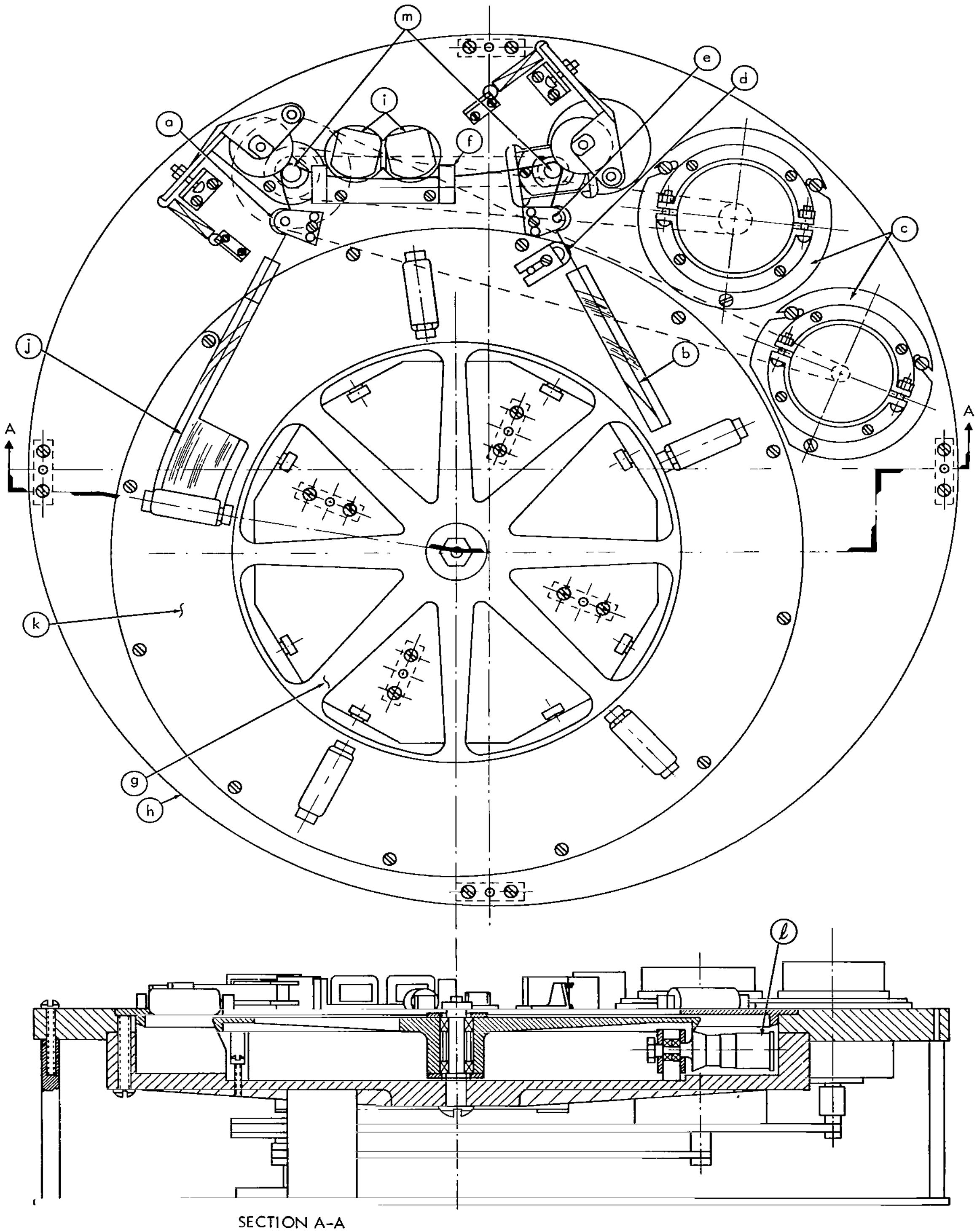


Figure 1—The 1200 ft endless-loop tape transport assembly.

played back in a total time of 8 min., completing one cycle of operation. It is also possible to utilize existing digital heads which make it possible to store eight channels of data on the 1/4 in. wide tape.

The use of dual capstans provides a constant tension across the heads, thus making possible the elimination of pressure pads and the consequent reduction in amplitude modulation, flutter, and skew.

MECHANICAL DESIGN

The mechanical design of the tape recorder is predicated on the following requirements:

1. An 8 to 1 speed ratio, i.e., tape speeds of 3-3/4 ips on record and 30 ips on playback,
2. A tape length of 1200 ft,
3. An operational life of 9 months,
4. Low flutter for both two speed and single speed record and playback,
5. Low mechanical power for both record and playback modes,
6. Survival of the required environmental testing.

These requirements led to major design advancements in records of this type and capacity.

Tape Transport

The transport is designed to conform to the tape cartridge (g) for optimum space utilization and maximum performance (Figure 1). Essentially, two cartridges were designed and tested. A detailed description is given later.

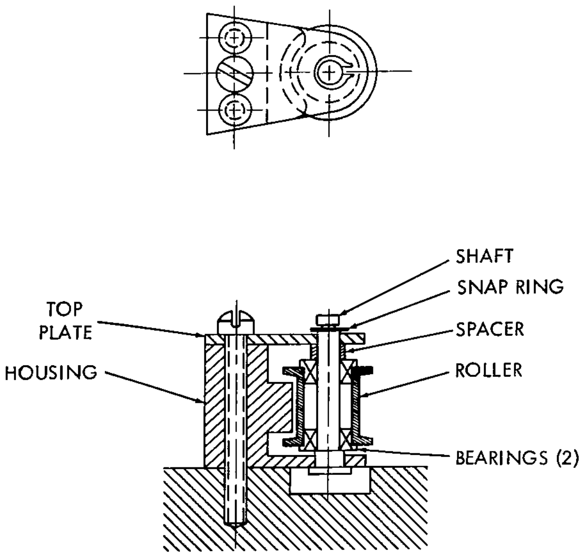


Figure 2—Tape guide roller assembly.

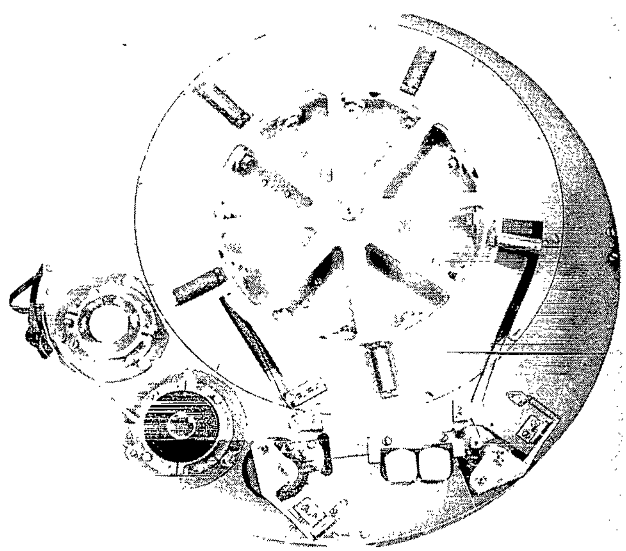
Two capstans (m), accurately machined for high precision, provide a constant tension on the tape between them and filter out minor disturbing pulses which could possibly be generated from the slippage of each layer of tape in the tape pack. The constant tension on the tape is produced by making one capstan diameter slightly smaller than the other. A speed difference of about 1 percent is used.

The magnetic heads (i) are placed between the capstan, inserted far enough to allow for positive head gap to tape contact. No pressure pads are used, although guiding the tape across the heads (f) improved alignment. Tape guide rollers (a), illustrated in Figure 2, are employed on both the tape entrance and exit sides to confine the tape to its proper position during performance and environmental testing. The motors (c) are located at the maximum distance from the magnetic heads. This is done to minimize the possibility of the heads being influenced by stray magnetic fields emanating from the motors, and to allow any mechanical vibrations set up by the motors to be damped by the top plate before reaching the heads. Although the exact motor or motors have not been selected at this writing, the positions indicated were established as the most likely locations.

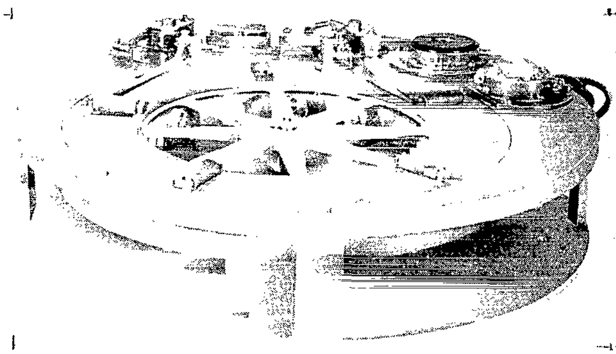
The use of K-1A magnesium for the top plate (h) construction provides internal damping which efficiently damps vibration induced by the rotating components.

Motors

It was not until a breadboard model of the 1200 ft recorder (Figure 3) and later a preprototype (Figures 1 and 4) were tested that the actual mechanical power required became known. The measurements were made by using both a calibrated dc motor and a tensiometer which measured the tensile force between capstans. At room temperature, for the record speed of 3-3/4 ips a power of 0.0717 watt is required, and for a playback speed of 30 ips a power of 0.897 watt is required. These values vary slightly, depending upon tape type, tape pack looseness, and temperature. The powers could easily be converted to torques required at the capstans—0.34 in.-oz. at record speed and 0.53 in.-oz. at playback speed. An attempt was made to use hysteresis synchronous motors, available from a Tiros recorder, as record mode motors on the



(a)



(b)

Figure 4—Two views of the 1200 ft tape transport.

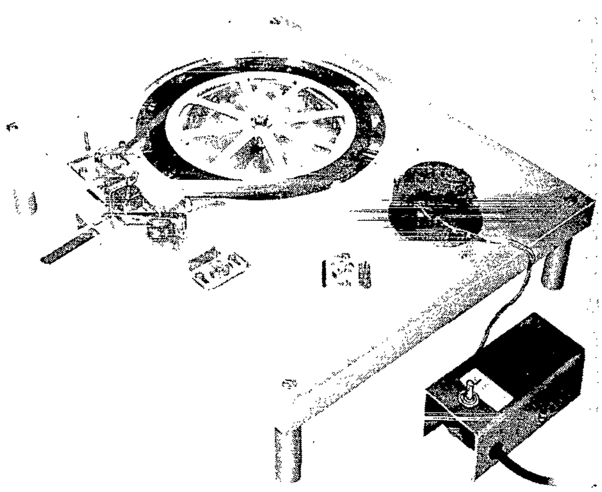


Figure 3—Breadboard model of the recorder.

preprototype model. It immediately became evident that the torque capacity of the motor was marginal and that severe hunt oscillations of 20 cps were causing unacceptable wow and flutter values. Several other models of hysteresis synchronous motors were tried, but all contributed significant flutter because of inherent motor oscillations. The use of flywheels and friction dampeners on some of the motors did not eliminate the pulsations. To solve the immediate problem of testing the preprototype recorder, a 3600 rpm motor, used for testing of the breadboard model, was used for the high speed mode. A previously mentioned hysteresis motor with the lowest flutter contribution was used for the record mode.

However, from the motor tests it was obvious that no motor was immediately available which could be utilized as either a record or playback motor. The requirements for a good tape recorder motor are sufficient driving torque and low instantaneous speed fluctuations. In addition, the tests indicated that the motors were possibly being affected by the slippage fluctuations in the tape pack being reflected back to the motor. Future testing will help to determine an optimum motor design.

Using power and performance data obtained from the preprototype tests, investigations have been initiated on obtaining dual speed motors of two types—hysteresis synchronous and brushless dc. The advantages of dual speed motors are elimination of one motor, higher reliability, since slip clutches are not required, and the reduction of possible additional flutter components which would result from an extra motor and extra pulleys. A brushless dc motor is preferred to a hysteresis synchronous motor for the following reasons:

1. The starting torques are similar to those of a dc motor,
2. The speed stability is the same as that of a hysteresis synchronous motor,
3. The efficiencies approach those of a dc motor,
4. The motor contains no brushes (a dc motor does), eliminating a wear and noise problem.

Belt Drives

Endless polyester film belts are used for the speed reduction and power transmission systems. These belts are efficient and accurate, and they minimize speed variations because of their uniform thickness. Their expected life is extremely high when designed properly, and their thickness (0.0015 in.) allows the use of small diameter pulleys.

Capstan Assemblies

Capstan assemblies (Figure 5) which contribute no more than 50×10^{-6} in. of total

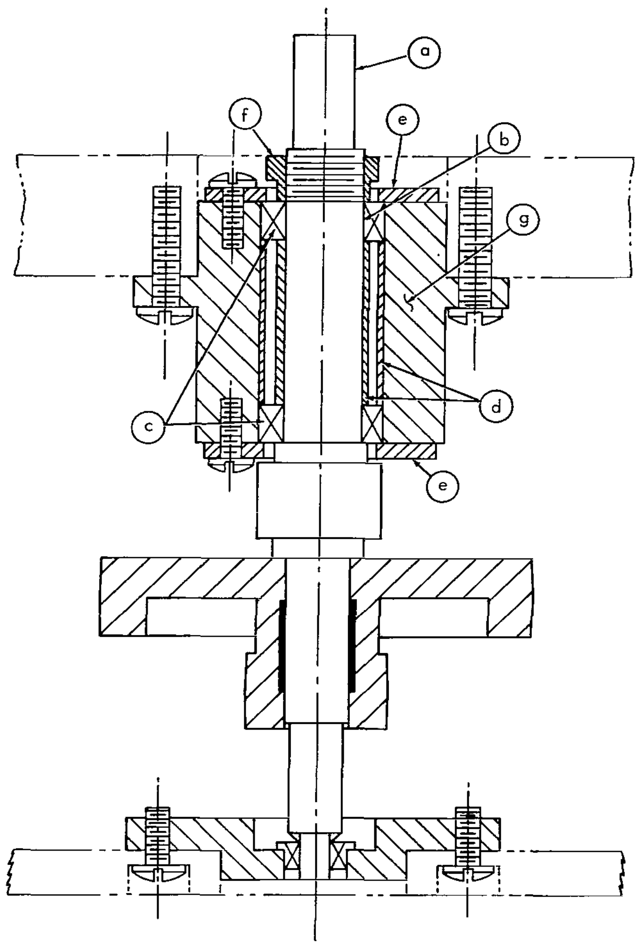


Figure 5—Capstan assembly.

indicated runouts (TIR) at the tape driving surface are required to minimize the flutter contribution due to velocity differences. The capstan diameter is 0.250 in., a size considered adequate to maintain low percentage velocity change due to runouts.

An attempt was made to obtain the low TIR by using extremely low runout duplex bearing pairs and grinding the shafts and housings to very low tolerances. If this method were successful, bearings damaged through vibration testing could be replaced with new ones of the same tolerances without discarding or reworking a complete assembly. After manufacturing, assembling, and testing several capstan assemblies in the preprototype recorder, it was found that it was not possible to consistently obtain and hold the required capstan runouts by this method. Although the tolerances with regard to diameter fit and the TIR on both the capstan diameter (a) and bearing inner races (b) were held extremely tight, there was a finite clearance in all fits. This allowed the shafts and inner race to be misaligned each time the preload was applied and, together with the machined TIR tolerances, the total radial runouts exceeded that required.

A grind-in-place technique was adopted to solve the problem. This consists, essentially, of assembling the duplex bearing pairs (c), bearing spacers (d), end caps (e), and capstan shaft (a) into the housing. The preload nut (f) is applied with enough force to preload the bearings and to prevent the inner race from rotating with respect to the capstan shaft. Caution must be exercised not to deform the races and damage the bearing. The final operation consists of shielding the bearings from external debris and grinding the capstan to the required final diameter and TIR. This is accomplished by holding the capstan housing (g) fixed and externally driving the capstan shaft while grinding in place.

Pressure Roller Assembly

The assembly's function is to maintain intimate contact between the tape and capstan. However, a preload system has been developed whereby a variable preload could be applied to the roller bearings without resorting to special duplex pairs, end caps, spacers, and captivating nuts. The preload was determined by applying just enough force to remove bearing play (Figure 6). This setting could then be locked in place. The spring force is applied through the center of the roller. By doing this, the possibility of cocking the roller and producing skew problems in the tape is minimized. An additional area of improvement was the elimination of a bulky viscous damper that existed on a Tiros damper. The original purpose of the damper was to prevent the roller from leaving contact with the capstan when the resonant frequency of the load spring was reached during vibration testing. At this point, the tape would ride up and off the capstan. To retain this function, the roller arm was adjusted so that, during vibration, the maximum distance the roller could back off was half the total roller compression on the capstan under the 24 oz. roller force against the capstan.

Tape Path

Figures 1 and 4 illustrate the path that the tape follows during operation of the recorder. The tape is 1.3 mil thick and coated with oxide on one side and lubricant on the reverse side; it has a polyester film base.

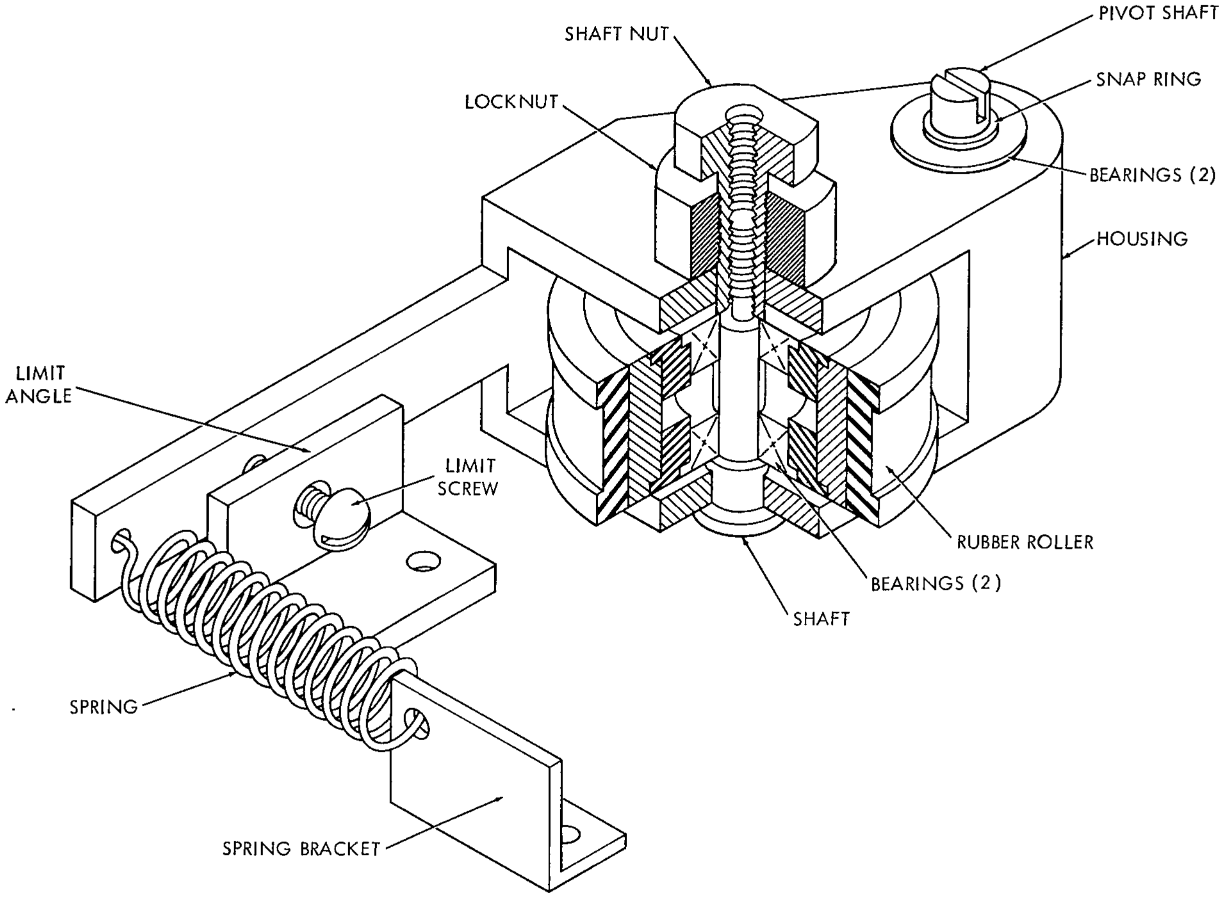


Figure 6—Rubber roller arm.

The tape is withdrawn from the inside of the tape pack (b in Figure 1), passing over the tape guide ramp (d) and through the guide roller (e) to the capstan (m). The capstans draw the tape through the tape guide (f) and across the erase and record-reproduce heads (i). The tape then passes through the final guide roller (a) returning onto the outer layer of the tape pack (j).

The differential angular velocity between the inner and outer layer of the tape pack results in interlayer tape slippage. This means that the individual layers of tape are slipping with respect to one another, maintaining tensions throughout the pack. This tension provides a means for drawing the tape back onto the pack after it leaves the capstan. Lubrication of the tape reduces the interlayer friction, thus reducing the flutter imparted to the tape and the amount of drive power required.

Tape Cartridge

The item which required the longest development time is the tape cartridge. The only cartridges in common usage had tape capacities from 200 to 300 ft. For designing a cartridge for 1200 ft of tape, various design considerations must be taken into account such as tape life, as defined earlier, transport operational life, performance requirements, and environmental testing. A 9 month life was a design requirement which allowed approximately 3 months of satellite testing on the ground and 6 months of operation in orbit. The life requirement and environmental testing were very severe on the tape; however, this will be discussed in another section.

The tape cartridge had to be designed so that it could effectively allow 1200 ft of magnetic tape to function properly. Such parameters as power, flutter, signal-to-noise ratio, and operation at two speeds for record and playback had to be taken into consideration in addition to the life requirement. The 9 months of continuous operation necessitated that the cartridge design impose a minimum wear condition on the tape. This meant that the tape must not suffer deterioration of the oxide, lubricant, and base material to the extent that its operation would be detrimental to the system as a whole.

The first approach to a cartridge design was to obtain an optimum mean diameter of the cartridge with minimum pack thickness. It is important to have a narrow pack thickness to minimize tape wear induced by the angular velocity difference between inner and outer tape layers. In addition, the mean tape diameter should be within reasonable limits to prevent an excessively heavy and large recorder design. From a curve of mean tape pack diameter vs. pack thickness for various lengths of tape (Figure 7) an optimum mean diameter of 8 in. was chosen for a pack thickness of 0.8 in. for 1200 ft of tape.

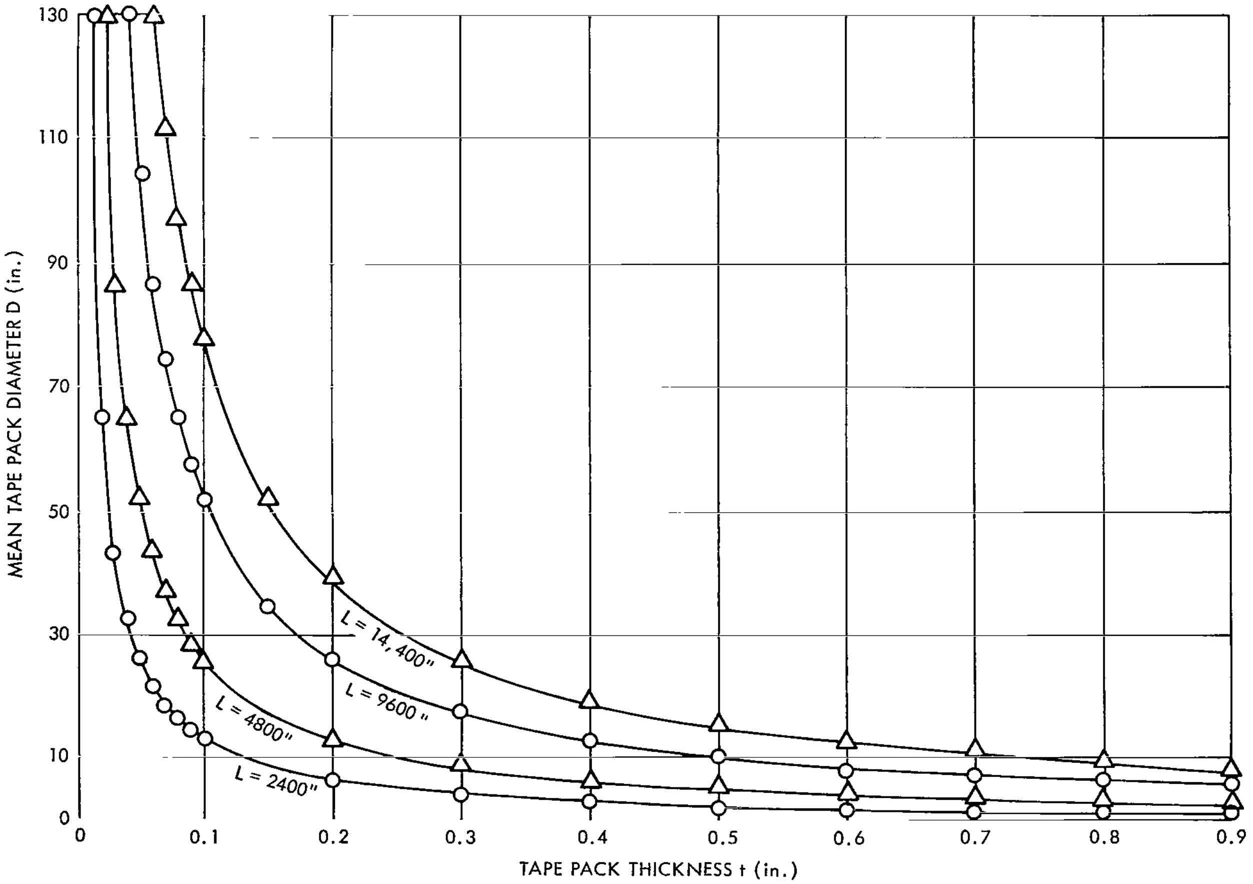


Figure 7—Mean diameter of the tape reel vs. tape loop thickness. $D = WL/\pi t$ where W is the tape thickness and L is the tape length.

After the basic size of the cartridge was determined, there were two design possibilities. One was to expand the Tiros type into a larger size. Also, as a result of preliminary tests, it was found that flutter was appreciably reduced when the tape was supported on rollers during operation. Thus the second design consisted of utilizing rollers to support the tape in the cartridge.

A large Tiros type of cartridge (Figure 8) was built and installed in the breadboard model for testing. Performance tests were run at various speeds. Although the cartridge appeared to function well, severe tape pulsations occurred which increased with tape speed. Therefore, this type of cartridge was eliminated from further consideration because the pulsations resulted from a condition of excessive tape friction between each layer and between the tape edges and reel flange. This causes accelerated tape wear and is detrimental to overall recorder reliability. Secondly, because of the magnitude of the pulsations filtering could not be easily accomplished with simple devices. This would result in large periodic flutter and wow disturbances.

At this point, the roller-reel tape cartridge was put into the breadboard model (Figure 3) and testing proceeded. The main problem area developed with the tape support rollers. The original

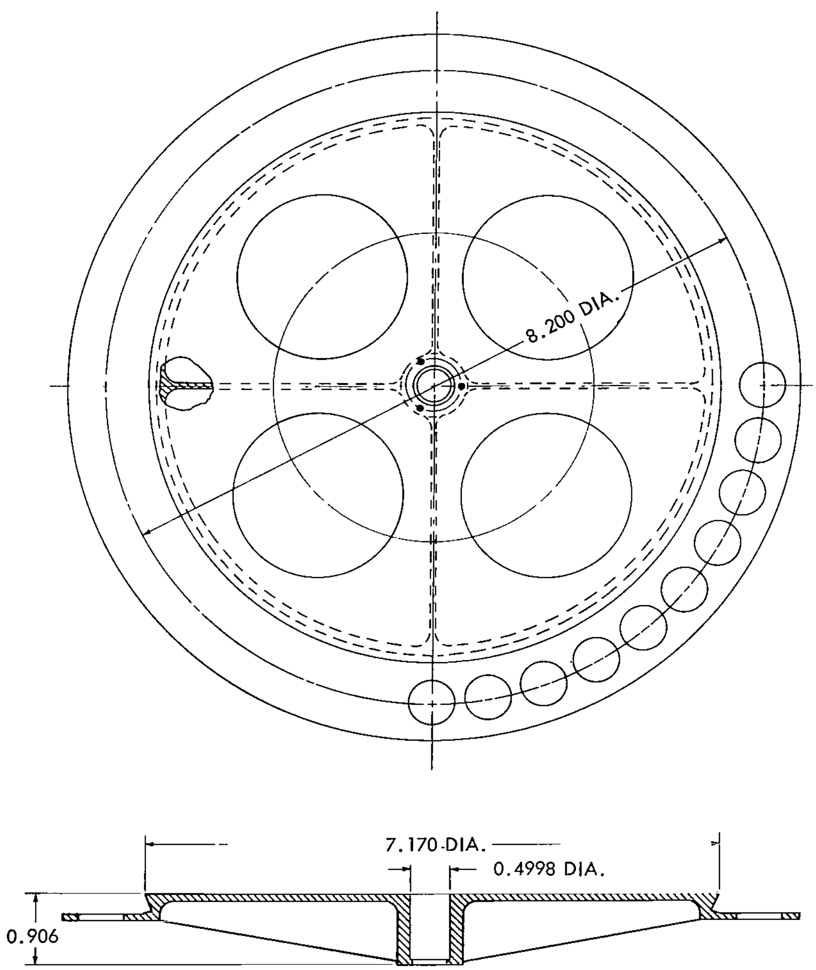


Figure 8—Tape reel and cross section.

rollers were straight cylinders. During testing, it was observed that upon acceleration the tape would form a loop on the return side which would not pull in and which remained at a constant length. This situation resulted because of the lack of friction between the outer layers of tape and the tape rollers. Friction did exist between the outer layers of tape and the flange of the larger Tiros reel. With the Tiros type of cartridge, the flange which supports the tape has a higher linear velocity than the tape itself at every point; therefore, there is a constant frictional force pulling the tape into the cartridge on the return side. This effect is absent with the rollers and actually works in reverse where the tape must drive the rollers. To correct this situation, a series of tests was conducted that resulted in two cylindrical steps being added to the straight roller section. It was found that the rpm of the rollers was determined at the smallest diameter which provides a higher circumferential velocity at the two larger steps. The resultant relative velocity between the roller and tape edge was sufficient to prevent the tape from forming and maintaining a loop on the return side of the cartridge. With this problem solved, the cartridge functioned uniformly; and it was decided that further recorder development would be centered around this cartridge.

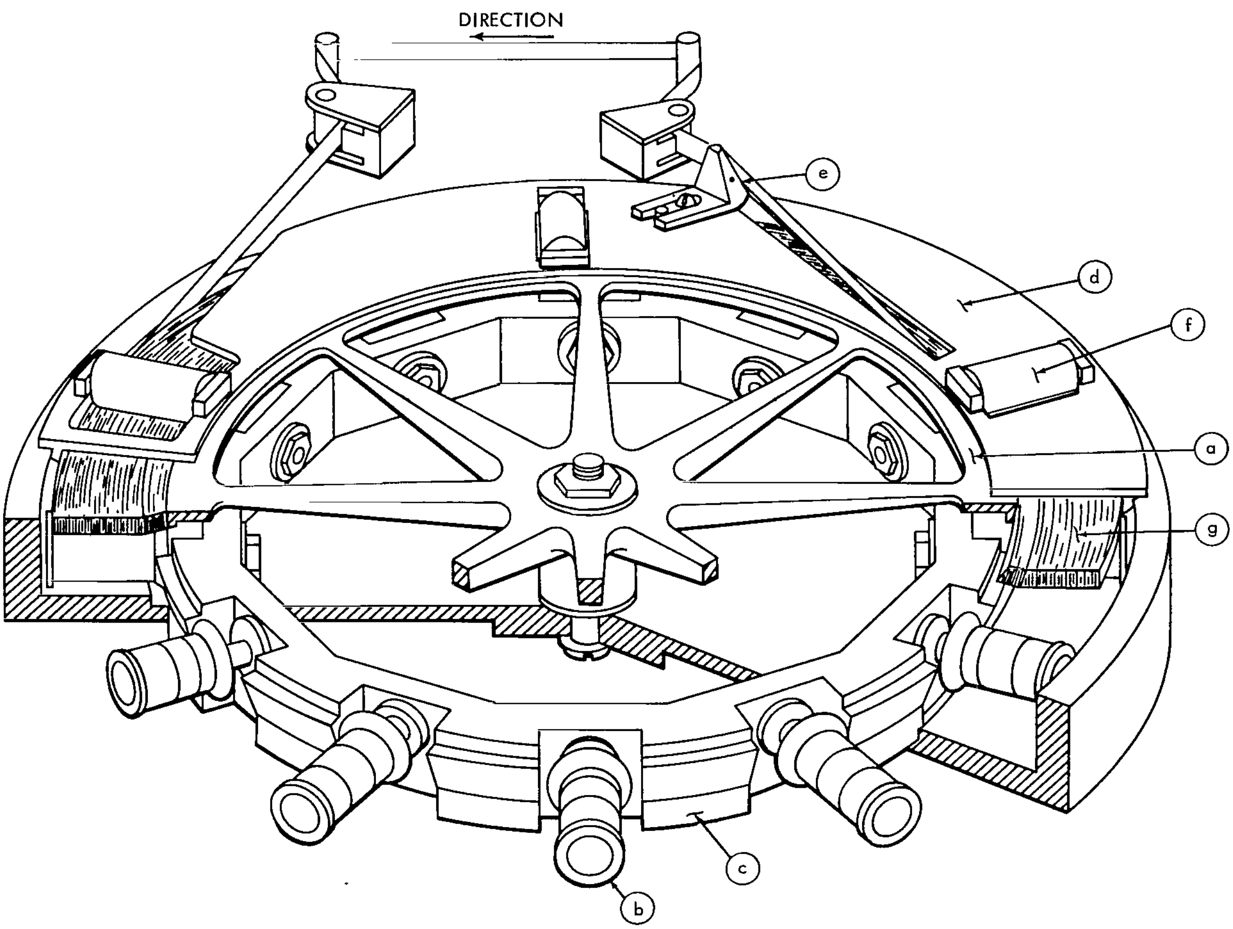


Figure 9—Tape cartridge.

The cartridge (Figure 9) consists of a tape reel (a), 12 tape support rollers (b), a roller mounting ring (c), a tape guide plate (d), a tapered guide (e), cover plate rollers (f), and, of course, 1200 ft of lubricated Mylar base magnetic tape (g):

1. Tape reel—Figure 10. It was found that if other than a cylindrical surface to which the tape pack conforms is used, the failure rate of the tape pack is very high. This is because wear increases at the areas where bending of the pack occurs (e.g., the 4 corners in a square pack). In addition, the cylindrical surface, with a profile such as this reel has, allows the tape to emerge from the cartridge with minimum tape disturbance due to flexure, edge wear, and oxide abrasion. This provides maximum performance and minimum wear. The reel is mounted in duplex bearings to insure a stable and smooth reel rotation and provide protection of the bearings during environmental vibration testing.

2. Tape support rollers—Figure 11. These rollers essentially comprise the "heart" of the tape cartridge. Twelve rollers were selected to prevent sagging of the tape between them and to obtain a circular tape pack.

As testing proceeded, it was determined that the two steps added to the straight cylindrical roller required vapor honing to increase the pull in force on the tape on the return side. Each roller is supported in two bearings in the roller mounting ring (Figure 12) which are not preloaded; however, the radial play of the bearings is limited to between 0.0001 and 0.0002 in. The bearings are lubricated with MIL-L 6085A oil. Preloaded bearings cannot be used; they cause intermittent rotation of the rollers. Each roller is made with the tapered portion of its cross

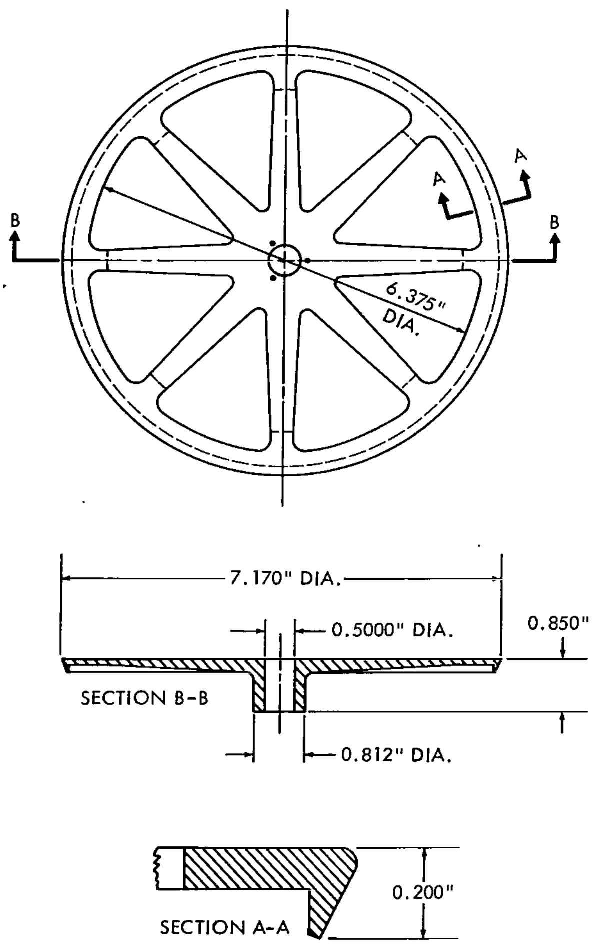


Figure 10—Tape reel.

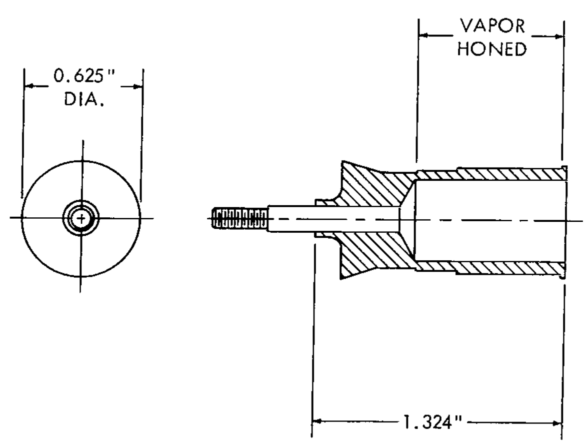


Figure 11—Tape support roller.

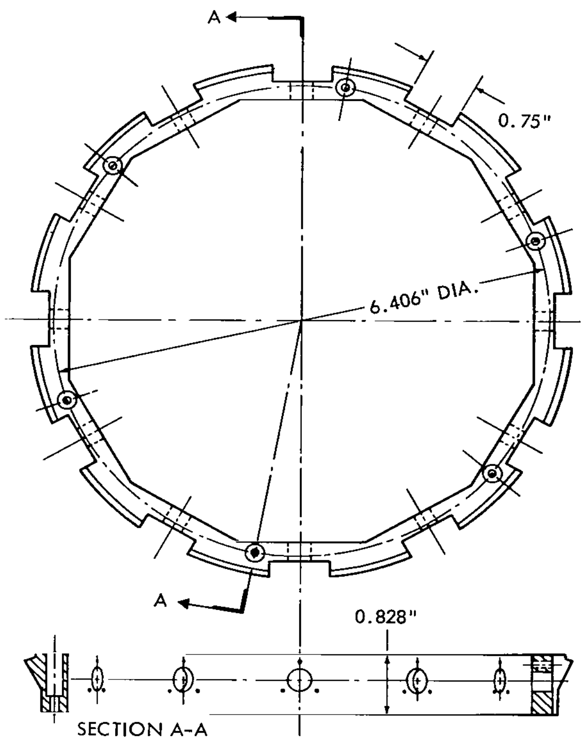


Figure 12—Roller mounting ring.

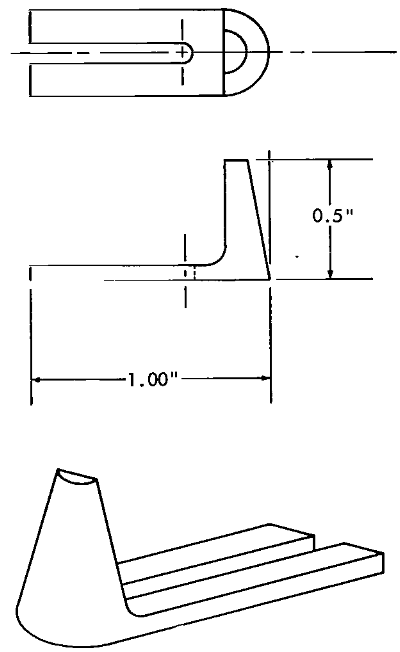


Figure 13—Tapered guide.

section nearest the reel. On both the reel edge slope and the roller taper, as seen in the profile section when assembled, the resulting cross section represents the attempt made to bring each layer of tape into an ideal position before it exits the cartridge. Thus, minimum strain and abrasion on the tape during the cartridge operation is exerted.

3. Roller mounting ring—Figure 12. The ring provides mounting of the tape support rollers and a meshing fit of the outer surface of the tape reel. This type of fit is a safety design to prevent the tape from possibly working its way between the conical portion of the tape support rollers and the tape reel edge.

4. Tape guide plate—k on Figure 1. The plate provides for mounting of the guide rollers which prevent the tape from rubbing on the underside of the plate when extraneous disturbances cause the tape pack to rise. In addition, this plate acts as a baffle to prevent debris from falling into the tape and cartridge.

5. Tapered Guide—Figure 13. The guide aids the tape in making the transition from an inclined to a horizontal position as the tape emerges from the cartridge.

TAPE SELECTION

Although the problem of obtaining a functionally operating endless-loop tape cartridge for 1200 ft of tape had been solved, an area which required investigation still remained. This area concerned the magnetic tape itself. The tape which was used for smaller endless-loop cartridges on the Tiros and Nimbus recorders was not satisfactory for use on the larger cartridge. Initial testing with this tape revealed deficiencies in the mechanical stability of the tape during temperature testing. Primarily, there were two temperature problems. The oxide binder became soft at 70°C and the tape had a very high shrinkage rate.

Temperature tests were run on the 1200 ft endless-loop cartridge using Minnesota Mining and Manufacturing Company's LR 1220 tape at 30 ips and temperatures of 0°C, 25°C, and 60°C. At 0°C, the transport operated when the recorder was placed in a plastic bag, flushed with dry air, and sealed before being brought down in temperature. This was necessary to prevent the cartridge from jamming. It is felt that this occurrence is due to ice condensing on the transport and tape.

At 25°C the cartridge performed satisfactorily. However, at 60°C the tape exhibited excessive interlayer friction. This interlayer interference caused the cartridge to tighten up and eventually jam. A series of tests was conducted to determine whether the oxide, lubricant, or both were causing the trouble. At about 70°C the sliding friction of oxide against oxide increased, but the sliding friction of lubricant against lubricant remained constant. At 100°C the same effect was noted. This fact was brought to the attention of the tape manufacturer, who conducted his own tests and found that the oxide binder was stable only up to about 80°C.

Although the recorder temperature test was run at 60°C, it is possible that the interlayer angular velocity difference causes a localized heating effect which raises the tape surface temperature above 70-80°C.

As a result of tests, the manufacturer provided new samples of tape (LR 1259 and 8943) which were considered identical in magnetic and lubrication properties to the LR 1220 but had a higher temperature binder on the oxide side. LR 1259 was tested at 60°C in the cartridge and operated considerably longer than LR 1220 at the same temperature, indicating the new binder was the solution to this problem.

However, at this point the second problem arose. When LR 1220 tape was used, the cartridge never operated long enough at the high temperature to observe other characteristics. As the LR 1259 continued to run at 60°C, it was observed that the tape pack was gradually tightening up. Finally, the point was reached where the pack became so tight that the cartridge jammed. This tightening process was attributed to the shrinkage of Mylar at high temperatures. This characteristic of Mylar is well known, but the exact rates of shrinkage were not as well known for various temperatures. Tests were run on LR 1220, LR 1259, 8943, and a tensilized tape sample to determine their shrinkage rates (Figure 14).

The percent shrinkage for LR 1259 at 60°C is 0.13 percent; however, if localized heating raises the temperature to 80°C, the shrinkage becomes 0.34 percent. For 1200 ft of tape and 0.34 percent shrinkage, the tape becomes shorter by 49 in., thus increasing tape tension excessively. The percent shrinkage for LR 1220 at 60°C is 0.075 percent and at 80°C it becomes 0.19 percent. For 1200 ft of tape with 0.19 percent shrinkage, the tape will lose 27.4 in. or about half that of LR 1259. The 8943 tape had a shrinkage rate of 0.13 percent. Base Mylar (0.001 in. thick) had a shrinkage rate of 0.284 percent.

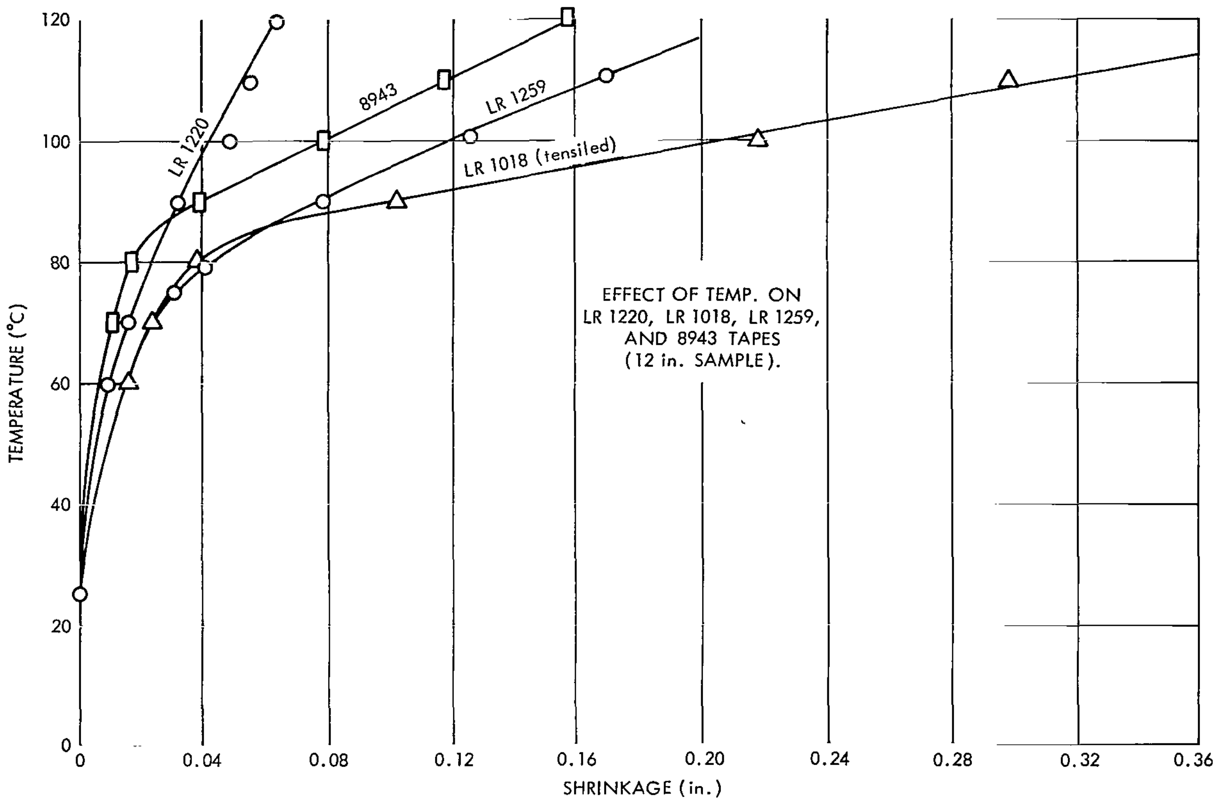


Figure 14—Effect of temperature on LR 1220, LR 1018, LR 1259, and 8943 tapes (12 in. sample).

Because these results showed large shrinkage rates and the variation of rates with tape type, it was decided to preshrink the LR 1259 tape at 100°C for 1 hour and then repeat the test in the cartridge at 60°C. After this the tape ran continuously at 60°C without any indication of tightening or jamming; however, during life testing a wear problem became apparent with the lubricant. Again the tape manufacturer studied the problem and supplied a new sample which passed the required 9 month accelerated life test. At present, this is the only tape which was found to satisfy the rigid temperature and life requirements. There were not enough samples to determine the recording characteristics although it was specified that the oxide should have the same magnetic properties as the tape it replaced. This new tape has the designation LR 1353.

PERFORMANCE CHARACTERISTICS

The specifications in Table 1 were taken with both the breadboard and preprototype models utilizing two motors, one for record and one for reproduce, not the flight model motors. In addition, the signal-to-noise ratio taken was obtained by observing the average signal level of a reproduced signal and then observing the amplitude noise associated with this signal. The standard technique of reading the residual noise level after the signal is erased was not used because the method utilized describes the functioning of the transport more accurately. That is, any disturbance due to skew, capstan misalignment, or pressure rollers that affects the tape contact with the heads will be noticed. Measurements on the preprototype model were taken only at room temperature because the motor arrangement did not allow enough room and flexibility to permit operation in the available environmental temperature chamber.

Table 1. Performance Specifications.

Measurement	Model				
	Breadboard			Preprototype	
Temperature (°C)	0	25	60	25	25
Record Speed (ips)	40	40	40	3-3/4	30
Reproduce Speed (ips)	40	40	40	30	30
Flutter (percentage p-p), 0-1000 cps	0.945	0.96	1.12	1.14	0.64
Power to Drive Entire System (watts)	1.29	1.00	0.640	0.0717 record 0.897 reproduce	0.897
Power to Drive Tape Alone (watts)	0.120	0.150	0.135	0.0207 record 0.170 reproduce	0.170
Signal-to-Noise Ratio (db)	22.4	22.5	24.4	40	-
Amplitude Modulation (percentage p-p)	-	-	-	-	3.8

From the data in Table 1 a distinct improvement is seen from the breadboard stage to the preprototype model. Although temperature tests were not taken at this time on the preprototype, it can be seen that temperature variations did not affect the breadboard excessively.

ENVIRONMENTAL TESTING

This transport has survived operation at 0°C and 60°C; however, when vibration testing was initiated, a problem of tape spew and tightening arose. Normally, in recorders of this type the motor is run to allow the major rotating assemblies which are mounted in ball bearings to rotate during vibration testing. This technique was attempted at various tape speeds with the transport isolation mounted, hard mounted, or with an assortment of tape guiding methods. Tests were also conducted with the motor not operating with negative results. Finally, the tape pack was held stationary by placing snubbers 180 degrees apart around the outside of the tape pack. They each exerted 3 lb of force on the pack. This method coupled with isolation mounting enabled the tape pack to remain stable during vibration testing; however, additional testing is required to prove the system. The isolation mounts limit the amplification at resonance to 4. If this method is used in the final models, the snubbing action will be applied utilizing solenoids which will make possible the release of the snubbing force after launch, to allow the recorder to become operational.

The following specifications are the vibration levels to which the recorder was tested:

1. Sinusoidal: 10 g, (limit to 1/4-in. single amplitude), 5 to 2000 cps, 18 min duration.
2. Random: 20 g rms, 20 to 2000 cps, 0.2 g^2/cps spectral density, 4 min duration.

CONCLUSIONS

The development of this transport, as described, does not contain equipment, designed for flight, such as electronics, motors, and a pressurized container, which would allow the transport to fly as a system in a satellite. As of this writing, no known recorders of this type have flown in a spacecraft. Future "in house" activities will consist of:

1. Testing the transport for possible application as a TV recorder in the meteorological program,
2. Reducing the overall cartridge and recorder design configuration to obtain minimum volume and weight, and
3. Designing a cartridge and transport to operate with 1200-ft of 1/2 in. tape.

Design and development efforts are continuing on an integrated transport system to include transport, electronics, enclosure, mounting techniques, etc. capable of surviving prototype environmental testing.

ACKNOWLEDGMENTS

The author wishes to express his appreciation for the major contributions of Messrs. William Burton and John Humphreys which aided in the design and development of this tape transport.

(Manuscript received October 29, 1963)

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